Hand Held Force Magnifier with Magnetically Stabilized Bidirectional Distal Force Sensor

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Purpose

A need exists for improvement in the perception of forces by the sense of touch when using tools to perform delicate procedures. This is especially crucial in microsurgery, where surgeons routinely repair tiny blood vessels under a microscope that are far too delicate to be felt by the hand of the surgeon, and ophthalmological surgery where delicate membranes are peeled off the retina using visual feedback alone.

Methods

We present a novel and relatively simple method for magnifying forces perceived by an operator using a tool, which we call the Hand Held Force Magnifier (HHFM). A sensor measures the force between the tip of a tool and its handle held by the operator's fingers. This measurement is used to create a proportionally greater force between the handle and a brace attached to the operator's hand, providing an enhanced perception of the force between the tip of the tool and a target. We have designed and conducted experiments with an initial prototype (Model-1), which magnifies pushing forces measured directly at the tip of the tool by means of a simple analog circuit. A second prototype (Model-2) uses a magnet based pre-load force and stabilization system to permit both push and pull forces at the tip to be measured proximally within the handle. The Model-2 integrates a computer using LabView™ to permit more complex controls such as stabilization and automatic calibration.

Results

Both the Model-1 and Model-2 are completely hand-held and can thus be easily manipulated to a wide variety of locations and orientations. The Model-1 sufficed for preliminary psychophysical evaluation, using a magnetically levitated haptics device from Butterfly Haptics™. The results showed that the HHFM could significantly enhance the users' perception of force and stiffness. The observed perceptual gain was close to the physical gain for detecting forces at threshold level, but slightly underestimated when judging stiffness and supra-threshold forces because of the saturation of the HHFM output. The new Model-2 provides a closer approximation to an actual surgical tool, because it permits both pulling and pushing at a smaller tip, which no longer contains the force sensor, thus simplifying a wide variety of possible tip designs for actual surgical utility.

Conclusions

Previous research using a robotic arm to produce force magnification has advantages in terms of stability, especially when encountering extremely small forces, but these systems suffer from constraints on the range of motion. Magnifying forces using the HHFM may provide the surgeon with an improved ability to perform delicate surgical procedures while preserving the flexibility of a hand-held instrument.